High Luminosity eRHIC: Linac-Ring Version

ERL: Main-stream - 5-10 GeV e^-

Up-gradable to 20^+ GeV e^-

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Linac-ring eRHIC

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http://www.agsrhichome.bnl.gov/eRHIC/

Appendix A of the eRHIC ZDR

Linac-Ring eRHIC.

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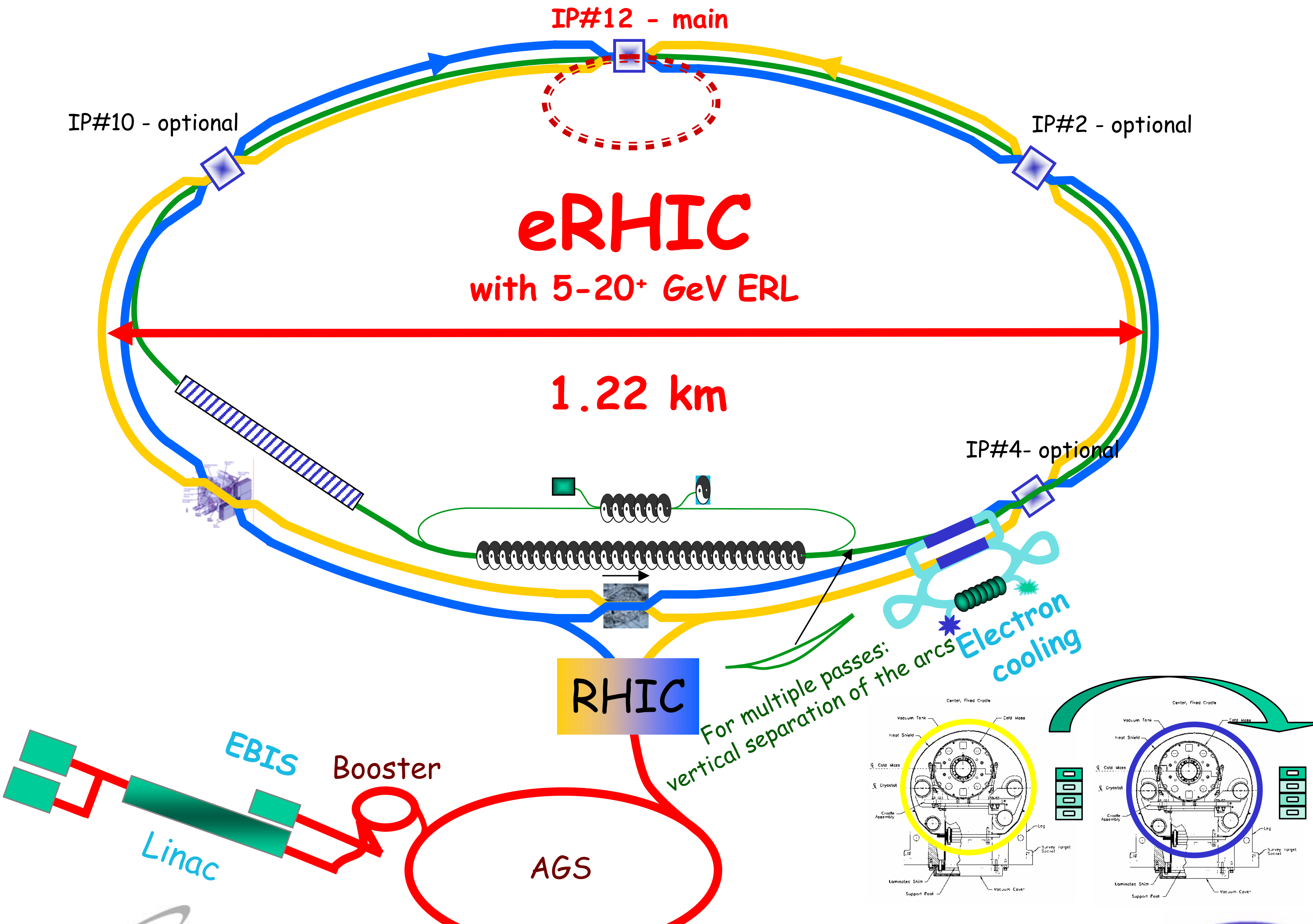
Outline

- **Layout(s) and Design(s),** **ERL ➲Detector without quads!**
- CM energies
- Beam parameters
- Luminosity : the values and the limits
- Polarization: the gun and spin transparency
- Lattice issues
- Conclusion

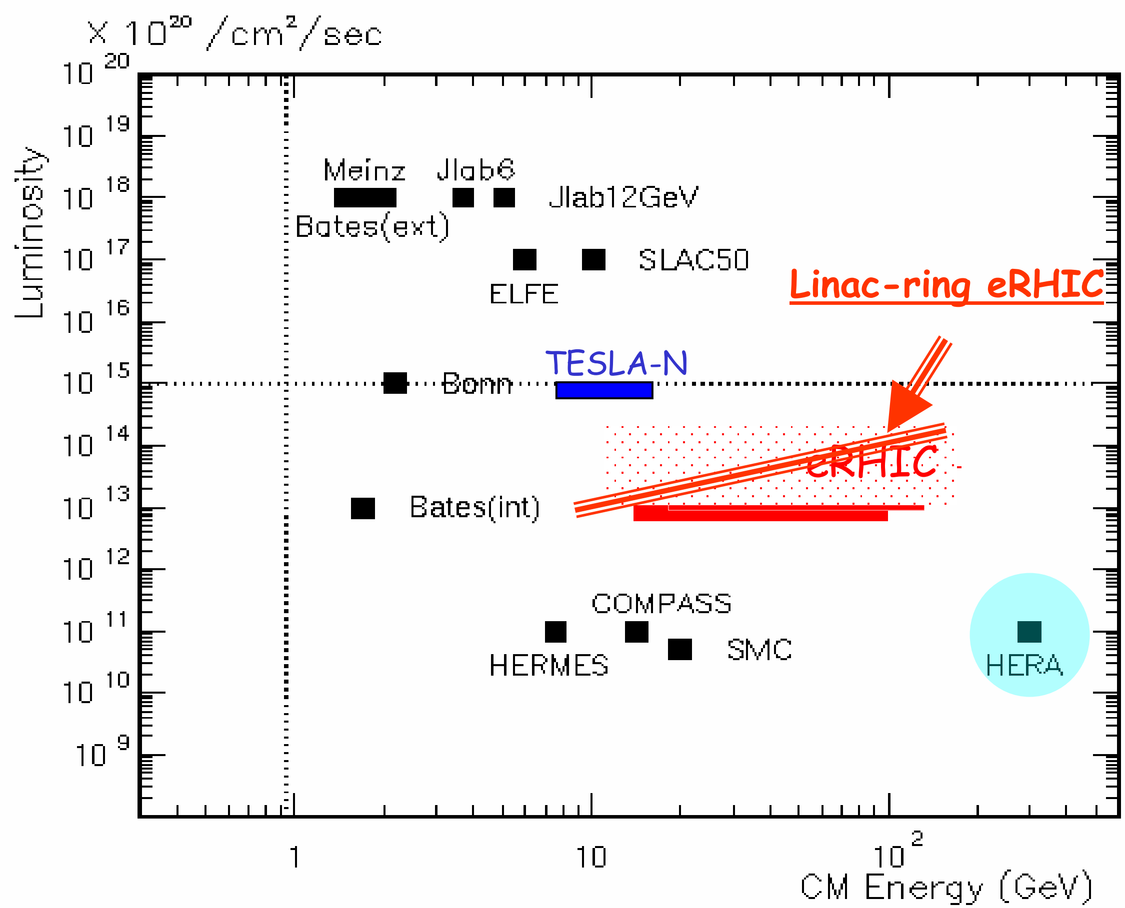

IP#12 - main
IP#10 - optional
IP#2 - optional
eRHIC
with 5-20+ GeV ERL
1.22 km
IP#4- optional
Electron cooling
For multiple passes: vertical separation of the arcs
RHIC
EBIS
Booster
Linac
AGS

Center-of-mass energies for linac-ring eRHIC

Energy, GeV **proton** / **electrons** c.m.	**26**	**50**	**100**	**250**
1	10.20	14.14	20.00	31.62
2	**14.42**	20.00	28.28	44.72
5	22.80	31.62	44.72	70.71
10	32.25	44.72	63.25	**100.00**
20	45.61	63.25	89.44	141.42
30	55.86	77.46	109.54	173.21

Energy, GeV **Au/u** / **e** c.m.	**50**	**100**
1	14.14	**20.00**
2	**20.00**	28.28
5	31.62	44.72
10	44.72	**63.25**
20	63.25	89.44
30	77.46	109.54

CM vs. Luminosity



eRHIC

- Variable beam energy
- Polarizes electrons and protons
- p-He^3-U ion beams
- Light ion polarization
- Large luminosity

Goals and Targets

- This scheme meets or exceeds the requirements for the collider specified in the physics program for eRHIC:
  - Electron beams colliding with beams of protons or light and heavy nuclei
  - Wide range of collision energies (E_{cm}/nucleon from 15 GeV to 100 GeV)
  - High luminosity $L > 10^{33}\ cm^{-2}\ s^{-1}$ per nucleon
  - Polarization of electron and proton spins
  - Preferably, two interaction regions with dedicated detectors.

Beam parameters

RHIC	main case	*option*
Ring circumference [m]	3834	
Number of bunches	360	
Beam rep-rate [MHz]	28.15	
Protons: number of bunches	360	*120*
Beam energy [GeV]	26 - 250	
Protons per bunch (max)	2.0 ¡ 10^{11}	*6 ¡ 10^{11}*
Normalized 96% emittance [µm]	14.5	
β^* [m]	0.26	
RMS Bunch length [m]	0.2	
Beam-beam tune shift in eRHIC	0.005	
Synchrotron tune, Qs	0.0028	
Gold ions: number of bunches	360	*120*
Beam energy [GeV/u]	50 - 100	
Ions per bunch (max)	2.0 ¡ 10^{9}	*6 ¡ 10^{9}*
Normalized 96% emittance [µm]	6	
β^* [m]	0.25	
RMS Bunch length [m]	0.2	
Beam-beam tune shift	0.005	
Synchrotron tune, Qs	0.0026	
Electrons:		
Beam rep-rate [MHz]	28.15	*9.38*
Beam energy [GeV]	2 - 10	
RMS normalized emittance [µm]	5- 50 *for $N_e = 10^{10} / 10^{11}$ e^- per bunch*	
β^*	~ 1m, *to fit beam-size of hadron beam*	
RMS Bunch length [m]	0.01	
Electrons per bunch	0.1 - 1.0 ¡ 10^{11}	
Charge per bunch [nC]	1.6 Š 16	
Average e-beam current [A]	0.045 Š 0.45	*0.015 Š 0.15*

Luminosity is determined by the hadron beam!

$$L = f_c \frac{N_e N_h}{4\pi\beta_h^* \varepsilon_h}$$

Round beams $\beta_e^* \varepsilon_e = \beta_h^* \varepsilon_h$

$$L = \gamma_h \cdot (f_c \cdot N_h) \cdot \frac{\xi_h \cdot Z_h}{\beta_h^* \cdot r_h}$$

$$\xi_h = \frac{N_e}{\gamma_h} \frac{r_h}{4\pi Z \varepsilon_h} = 0.007$$

Luminosity 10^{33} cm^{-2}sec^{-1}	*Protons 26 GeV*	*Protons 50 GeV*	*Protons 100 GeV*	*Protons 250 GeV*
Electrons 5(2)-10(20) GeV	**0.28**	**0.52**	**0.96**	**2.8**

Luminosity (per nucleus) 10^{31} cm^{-2}sec^{-1}	*Au 50 GeV/u*	*Au 100 GeV/u*
Electrons 5(2)-10 GeV	**1.4**	**2.8**

Dedicate eRHIC mode with 250 GeV p or 100 GeV/u Au

$$\xi_h \rightarrow 0.024 \quad \Leftrightarrow \quad L_{p\ e} \rightarrow 1 \cdot 10^{34}$$

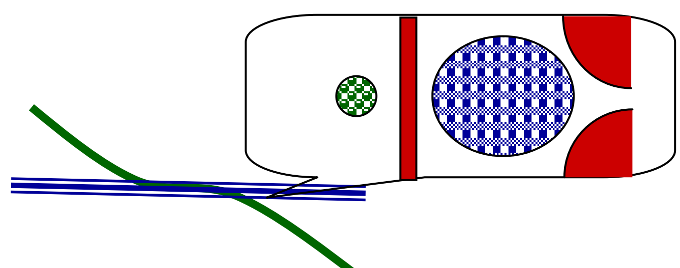
Advantages

- Usage of a fresh electron beam and absence of the memory in the e-beam
- Practically waves the limitation on the tune shift in the IP and increase in the intensity of proton/ion beam
- **Increase in luminosity by 2-to-10 fold**
- **Multiple Ips**
- **Larger β*for e-beam and simplified IP geometry**
  - smaller e-beam emittance & smaller angular divergence in IP
  - smaller aperture for e-beam
  - **no-need for e-beam quads in the detector area**
  - possibility to focus e-beam after separating it for protons/ions
- Eeduced number of coupled bunch instability modes
- **Absence of "prohibited" energies for the e-beam**
- Full spin-transparency of the system & high (>80%) degree of e-beam polarization at all energies
- No need of preserving beam qualities (polarization, emittance…) after the IP(s)
  - simple geometry of the return pass
  - absence of spin-resonances
  - possible multiple collisions (IPs)
- Usage of the linac (ERL) geometry
  - Easy adjustment the e-beam rep-rate to the beam rep-rate in the RHIC which significantly depends on the ion energy (equivalent change in circumference is ~ 3m);
  - Easy future e-beam energy upgrades
  - Possibility of using multiple energy collisions
  - Possibility of 10 GeV γ-ray source and γ- ion collider

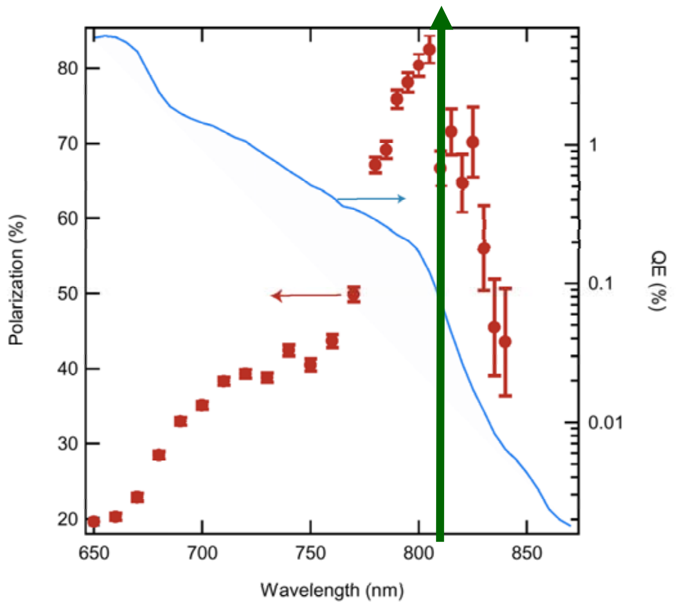
Integration with IP

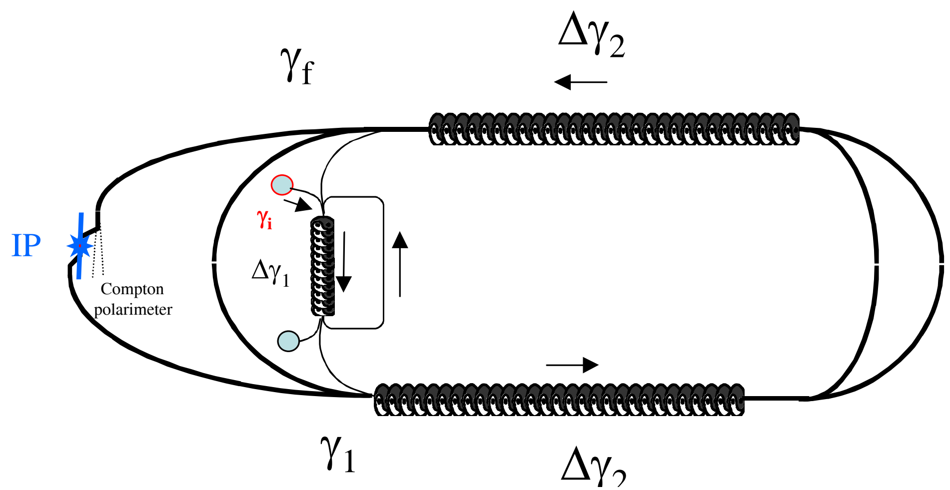
$E_x = 12\sigma_{p,x} + \mathbf{5\sigma_{e,x}} + d_{septum} = 12$ ¿ $0.93mm + \mathbf{5}$ ¿ $\mathbf{0.25mm} + 10mm = 22.4mm.$

- Round-beam collision geometry to maximize luminosity
- Smaller e-beam emittance resulting in 10-fold smaller aperture requirements for the electron beam*
- Possibility of moving the focusing quadrupoles for the e-beam outside the detector and the IP region, while leaving the dipoles used for separating the beam
- Possibility of further reducing the background of synchrotron radiation

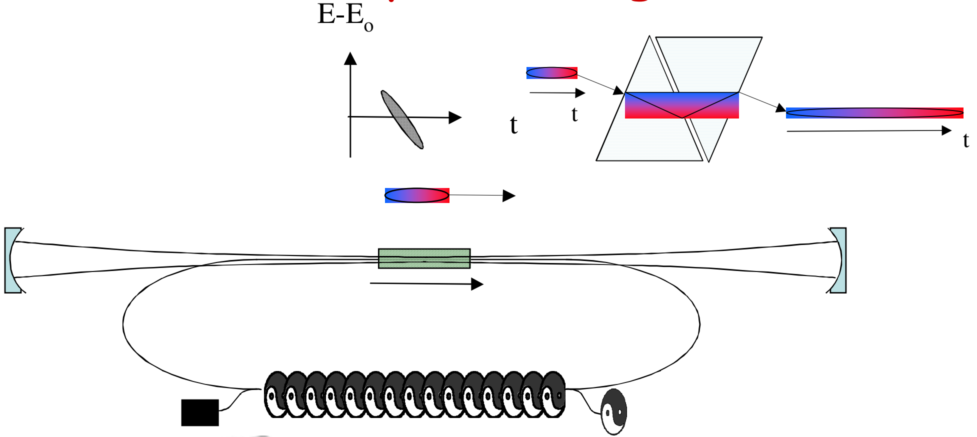


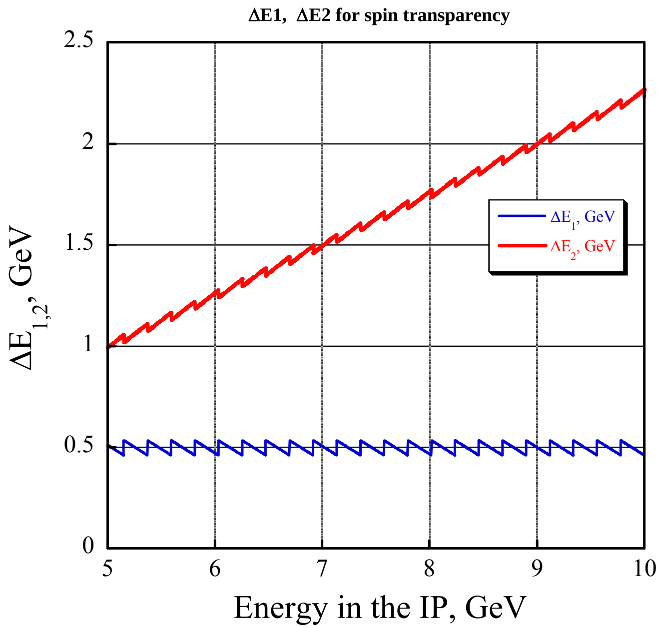
Polarized electron gun and ERL spin transparency

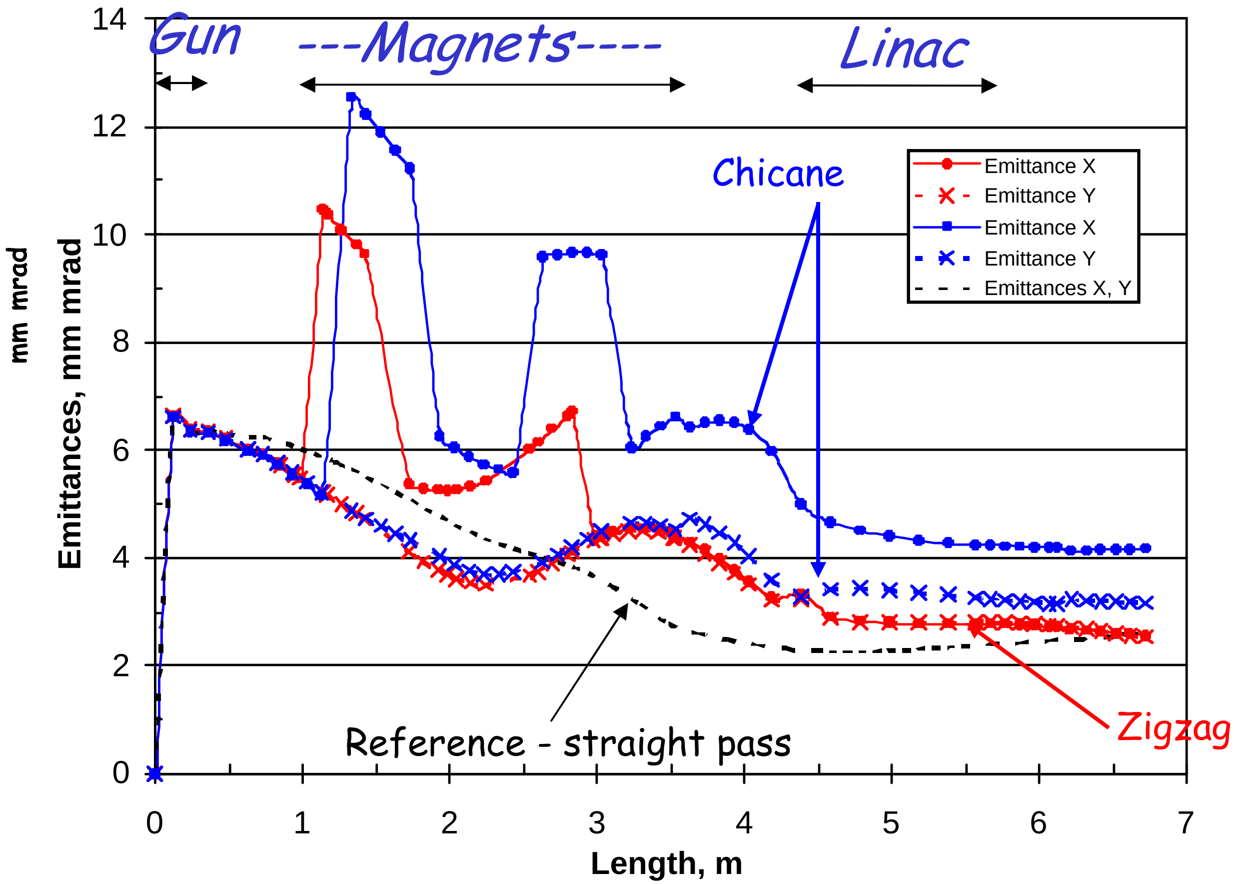




2KW FEL for polarized gun



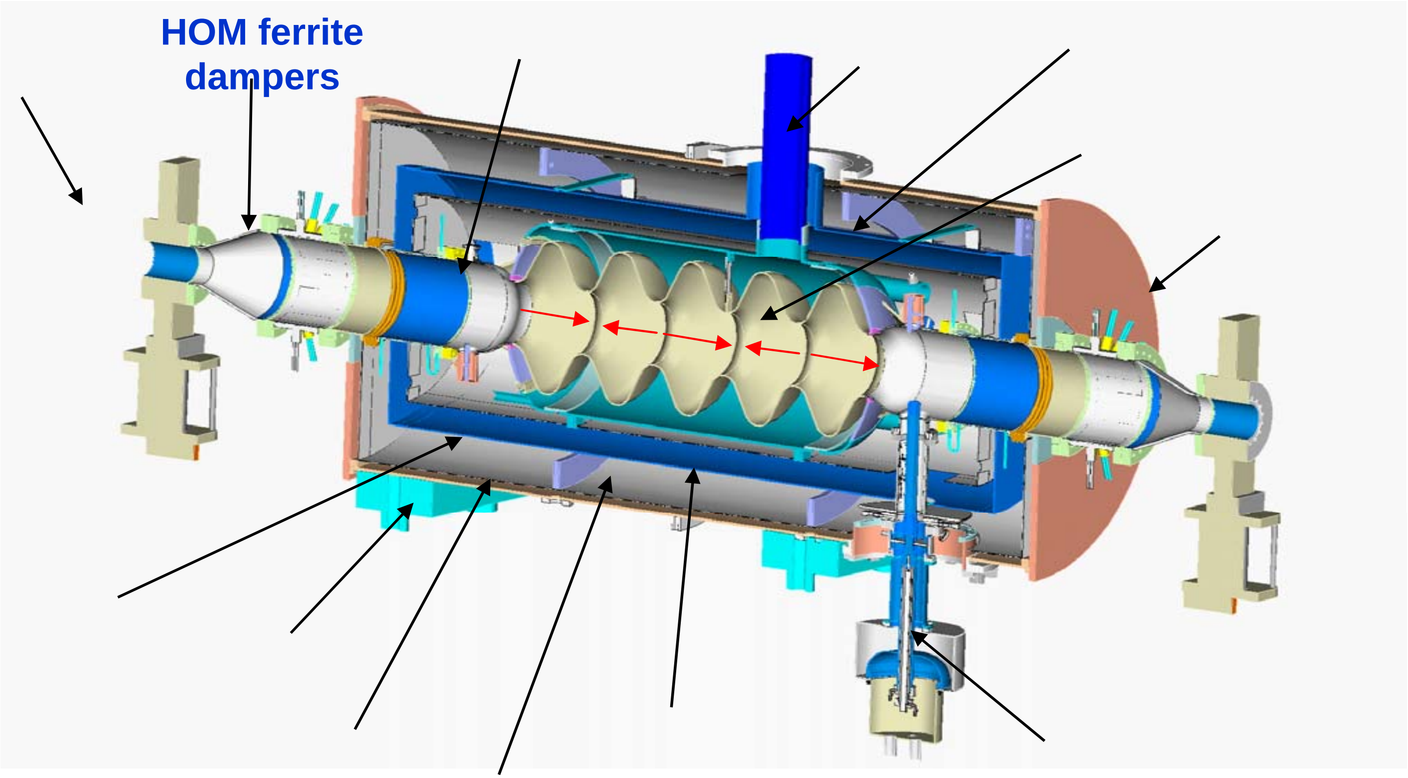




Results of Parmela simulation for 1 nC e-bunch from the cathode to the end of the linac: black dashed curve is for a round beam passing without bends; blue curves are for a compensated chicane, red curves are for Zigzag merging system.

In contrast with traditional chicane where horizontal emittance suffers some growth as result of the bending trajectory, the Z-system (zigzag) the emittances are equal to each other and are very close to that attainable for the straight pass.

RF accelerators

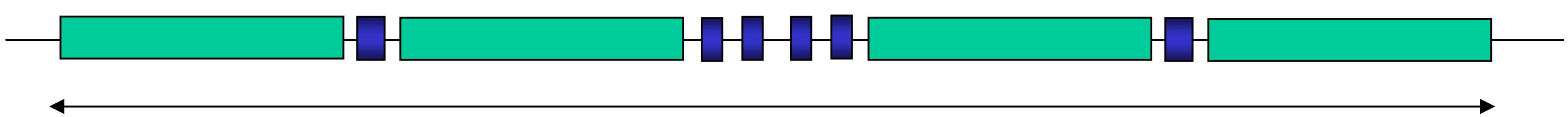


eRHIC - spontaneous radiation
Very few facts

Energy	20	10	GeV
Bρ	666.67	333.33	kGs m
Loss per turn	35.40	2.21	MeV
Power	**17.70**	**1.11**	**MW**
λc (reg. bend)	0.28	2.24	Å
E ph critical (reg. bend)	44.35	5.54	KeV

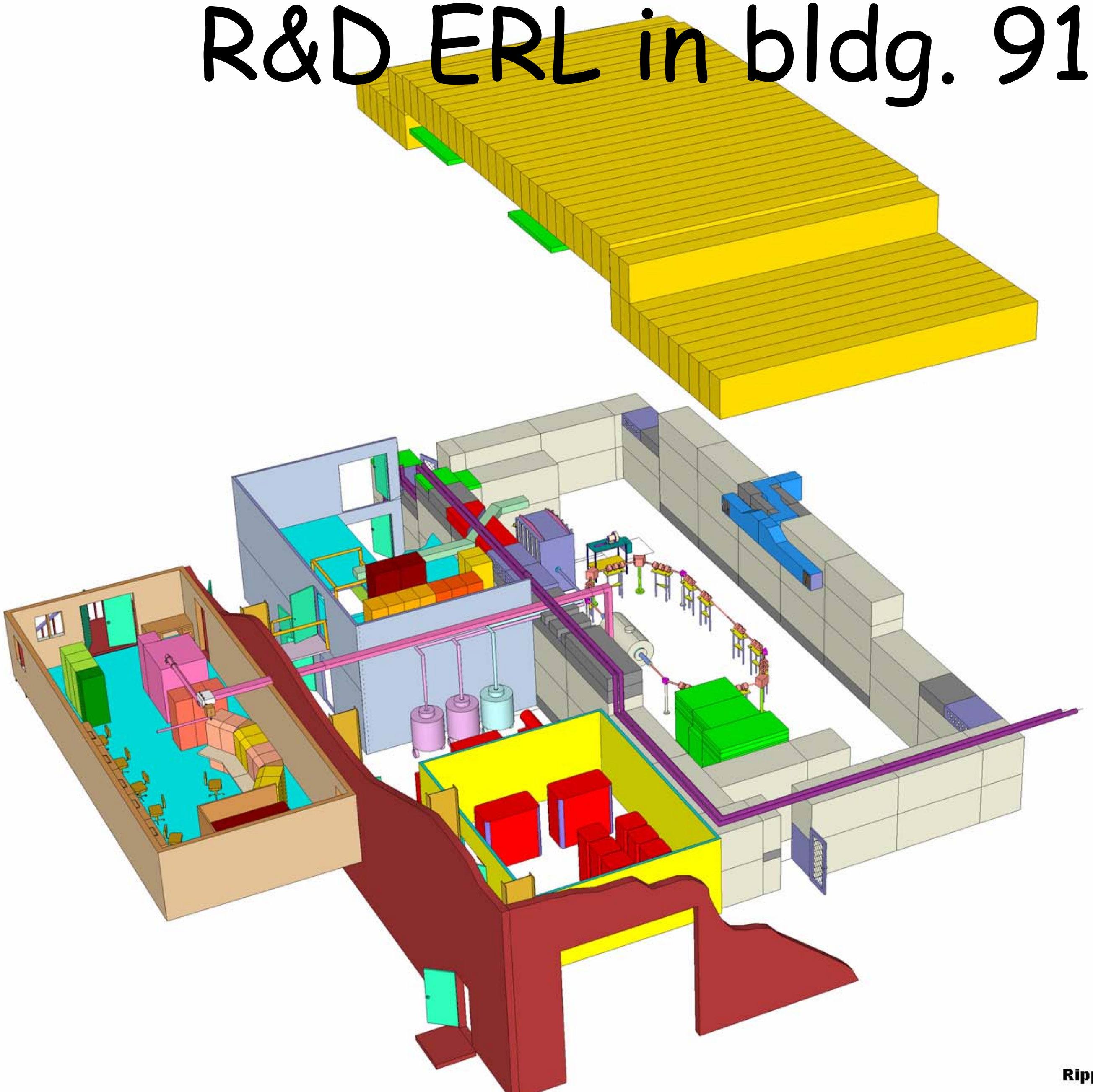
Beam parameters

Energy	**20**	GeV		Energy	10	GeV	
γ	3.91E+04			γ	1.96E+04		
Circumference	**3834**	m		Circumference	*3834.00*	m	
R, average	610.20	m		R, average	*610.20*	m	
% fill	65.55%			% fill	*65.55%*		
R magnets	400.00	m		R magnets	*400.00*	m	
B	1.67	kGs		B	0.83	kGs	
N TBA cells	**150.00**			N cells	*150.00*		
ε_{norm}	9.50E-07	m rad		ε norm	*9.50E-07*	m rad	
ε	**0.243**	**rad**		ε	**0.485**		
Bunchlength	**from 0.1 to 2**	**psec**		Bunchlength	**from 0.1 to 2**	**psec**	
Damping time	1.45E-02	sec		Damping time	1.16E-01	sec	
Revolution time	1.28E-05	sec		Revolution time	1.28E-05	sec	
Δε (TBA)	***0.016***	□ ***rad***	***6.70%***	***Δε (TBA)***	***0.001***	□	***0.10%***
ε	**0.259**	**rad**		ε	**0.486**		
RMS energy spread	2.54E-05			RMS energy spread	4.49E-06		



25 meters TBA cell

R&D ERL in bldg. 912



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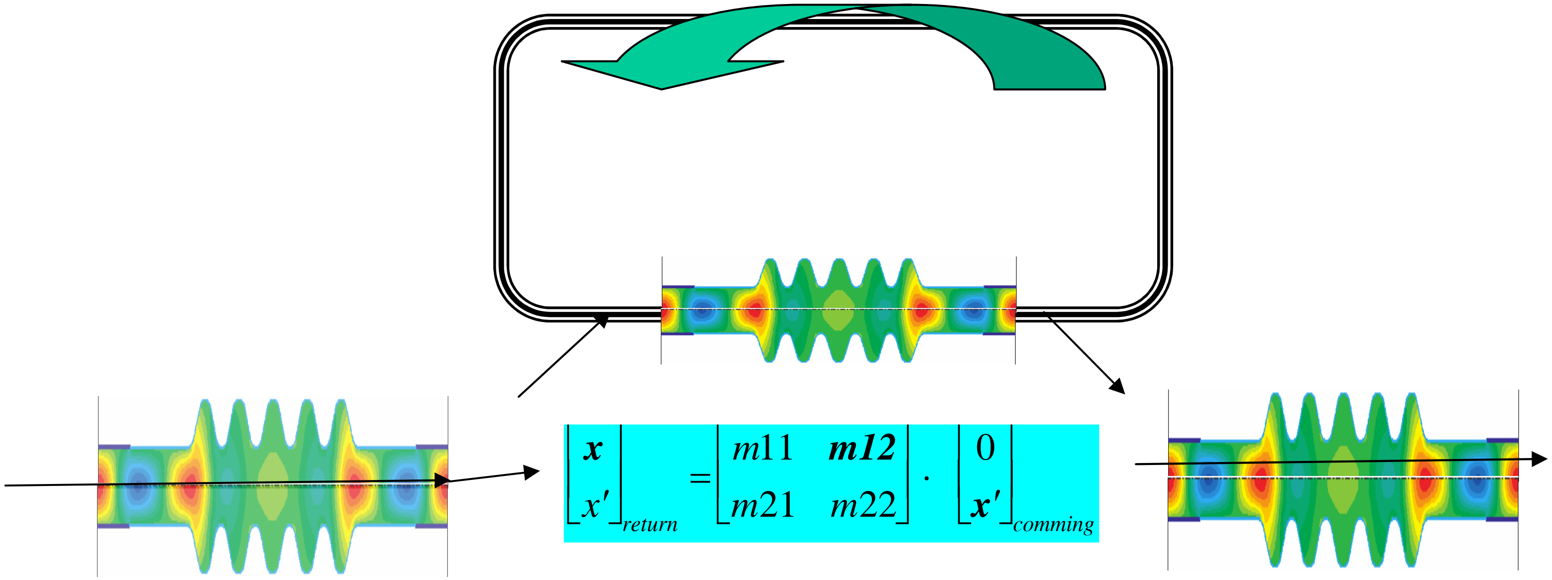
RHIC

Conclusions: It is feasible - Needs R&D

- Wide range of collision energies (E_{cm}/nucleon from 15 GeV to 100+ GeV. e^- energy as low as 1 GeV as high as 30 GeV).
- High luminosity
  - 10^{34} cm^{-2} s^{-1} for high energy protons,
  - 10^{32} cm^{-2} s^{-1} for high energy Au ions.
- High degree of polarization (>80%) of the electrons at any energy, no forbidden energies.
- One, two, three … interaction regions with dedicated detectors
- Energy of electron is simply upgradeable.
- Reduction of synchrotron radiation in detector by cooling ions.
- No quadrupoles in detector.
- Simple compensation for ion velocity.
- Possibility of γ-ion collider.

Multi-bunch Instabilities



$$\begin{bmatrix} \boldsymbol{x} \\ x' \end{bmatrix}_{return} = \begin{bmatrix} m11 & \boldsymbol{m12} \\ m21 & m22 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ \boldsymbol{x'} \end{bmatrix}_{comming}$$

Excitation process of transverse HOM